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Modeling and Simulation of Downlink Subcarrier Allocation Schemes in LTE

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Abstract
The efficient utilization of the air interface in the LTE standard is achieved through a combination of subcarrier allocation schemes, adaptive modulation and coding, and transmission power allotment. The scheduler in the base station has a major role in achieving the required QoS and the overall system performance. The resources for both downlink and uplink transmission need to be assigned such that the capacity, throughput, and cell edge performance are optimized. This paper investigates allocation schemes for downlink transmission based on different criteria and performs evaluation through simulation results. The system for downlink scheduling is modeled using OPNET Modeler.

Introduction
Not only because of the technology but also because it fulfills defined requirements for a pure 4G generation and backward compatibility with its previous generations (GSM, UMTS…), 3GPP Long Term Evolution (LTE) is leading the wireless mobile world. To achieve higher bandwidth, required spectrum deployment, increased spectral efficiency, flexibility and, consequently, a better QoS, the air interface of this all-IP-based network architecture utilizes the SC-FDMA in the uplink and OFDMA in the downlink enhanced by multiple antenna systems, supporting both the time (TDD) and frequency (FDD) division duplex modes. One of the main factors providing for a reduced latency is that LTE uses a relatively simplified network infrastructure consisting of only two nodes: the enhanced NodeB (eNB) and the mobile management entity/serving gateway (MME/S-GW). Thus, protocol processing overhead is reduced, leading to a reduced latency [1]. Due to the all-IP based architecture, the air interface needs to accommodate a mixture of real and non-real time services. In order to support mixture of services with different QoS demands, an end-to-end class based QoS architecture has been defined for LTE. During setup of radio bearers, the eNB needs to assign the necessary QoS class to the radio bearer. Each QoS class is characterized by: resource type (guaranteed and non-guaranteed bit rate), priority, packet delay budged and acceptable packet error loss rate.

In such a constellation, LTE operates as a scheduled system (on the downlink shared data channel), which means that all traffic, including delay-sensitive services, needs to be scheduled. The main purpose of the LTE scheduling system in the Base Station (BS) is to prioritize and allocate the available frequency-time resources to specific single user equipment (UE). The scheduling is at the MAC (Medium Access Control) layer, it is not standardized and it is an implementation specific mechanism. Therefore, the scheduling is an important issue and the main factor to influence the system performance and reusability of the resources [3]. The design of a downlink scheduling algorithm is a complex procedure and presents a number of design challenges, such as maximization of system capacity and spectral efficiency, bit error performances, fairness approach, etc.

So far, there has been a lot of research in modeling the scheduler in order to achieve the highest performance while avoiding latency and starvation problems. For the sake of model diversity and testing for our OPNET implementation, we tried to simulate and analyze different scheduling algorithms. In particular, we show that the MAC scheduler needs to be aware not only of channel conditions but also of different QoS classes. Additionally, a buffer-aware based algorithm is proposed, and the results are compared with the maximum capacity algorithm. The algorithms are evaluated on different criteria, such as achieved throughput and delay for each type of service.

This paper is organized as follows. In section II, we give some general insights on scheduling algorithms present in the literature. In section III, we describe our OPNET implementation of the downlink scheduling framework. In the following section, the traffic source parameters are presented. The fifth and sixth sections deal with the MAC layer implementations at the UEs and eNB. In section VII, the simulation parameters are presented, while the next section provides a discussion of the simulation results. Concluding remarks are offered in the last section.

Overview of Downlink Allocation Schemes
In this section we give a brief overview of downlink allocation schemes based on [2], [4], and [6]. The MAX CQI (Channel Quality Indicator) algorithm exploits multi-user diversity, such that users who have the best channel conditions are prioritized. This scheme increases the system capacity, but fairness and delay requirements for real-time services are not achieved by this algorithm. Users located on the cell edge may not be scheduled for a longer time. The proportional based algorithm provides fairness among users. The algorithm can be designed to provide fairness in terms of throughput, and additionally can consider the delay requirements.

In the above described scheduling schemes, the CQI feedback is considered by the scheduler. Additionally, the scheduler can be designed to take into consideration the transmission buffer size, which represents the data available for scheduling. Such buffer-aware scheduling can significantly improve the performance, as well as reduce resource utilization.

LTE Downlink Scheduler Design

In this work, OPNET Modeler has been used in order to develop a simulation model for the LTE Downlink Framework. OPNET Modeler provides the means for simulation-based research for different standards, among which is LTE. When the downlink scheduling is considered, only a set of functionalities are required. As such, the following models are utilized: an LTE physical layer for physical transmissions, MAC layer responsible for scheduling, and a simplified RLC layer that is responsible for creating MAC SDUs. Our main contribution is on the MAC layer, while the actual physical transmission has been adopted from the OPNET LTE model. Figure 1 depicts the LTE node model used in this project, which is common for the eNB and the UEs. Since only downlink is considered, the Traffic Source module is disabled at the UE nodes.

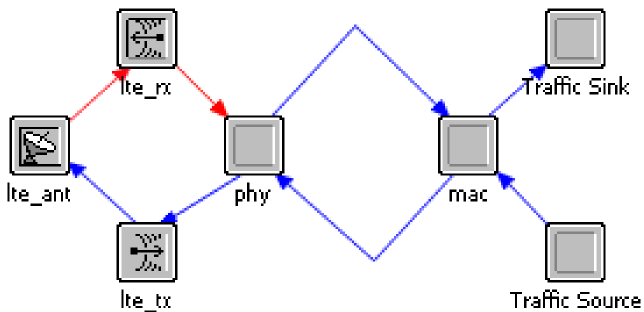

Figure 1 Basic LTE Node Model

The "mac" processor modules have different tasks at the eNB and the UE and they are described separately. The "phy" module is the same at the UE and eNB. It is responsible for transport channel processing such as applying modulation, coding rate, etc. In this phase of the project, packet loss has not been considered. The pipeline stages for error correction have been modified such that all packets are assumed to contain no errors.

Traffic Source Parameters

Table 1 shows the traffic parameters for each service that has been considered during the simulations, and it is based on [7][8][9].

VoIP		
Parameter	**Distribution**	**Assumption**
ON period	Exponential	Mean 2 sec
OFF period	Exponential	Mean 2 sec
Inter-packet rate	Constant	0.02 sec
Packet size	Constant	31 bytes
SID frame packet size	Constant	15 bytes
SID inter packet rate	Constant	0.16 sec
Video		
Inter-arrival time of frames	Deterministic	0.1 sec
Nr. of packets in a rame	Deterministic	8pkts
Packet size	Truncated Pareto (Mean= 100bytes, Max= 250bytes)	K = 40 bytes α = 1.2
Inter-arrival time between packets (slices) in a frame	Truncated Pareto (Mean= 0.006s, Max= 0.0125s)	K = 2.5ms α = 1.2
HTTP		
Packet Size	Pareto	Mean 81.5 bytes Shape 1.1
Inter-arrival time	Normal	Mean 0.0277 sec St.dev 0.01sec
Session Size	Normal	Mean 25 packets St. Dev 5 packets
Reading Duration	Exponential	Mean 5 sec.
FTP		
File size	Truncated Lognormal Max= 5MBytes	Mean = 2Mbytes Std. Dev. = 0.722 Mbytes
Reading time	Exponential	Mean 180 sec

Table 1: Traffic Source Parameters

Each traffic type is represented by a separate process, such that the main traffic source dynamically creates each process depending on the simulation parameters: radio bearer per UE, start and stop time, etc. The purpose for choosing mixed data traffic is to show the scheduler design impact on the QoS and different services.

UE MAC Process Model

The functionality of the UE is to process the received downlink data from the eNB in order to report statistics and to generate CQI feedback to the Scheduler. The UE measures the effective SNR over the entire bandwidth. It is assumed that the CQI are available to the eNB with no delay. The mapping between the measured SNR and the CQI report with a target BLER (Block Error Rate) value of 10% is approximated through the linear function depicted in Figure 2 [10].

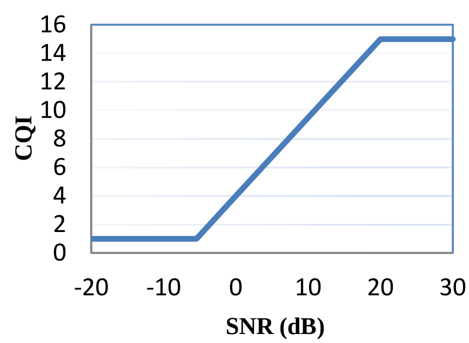

Figure 2 SNR to CQI Mapping Model

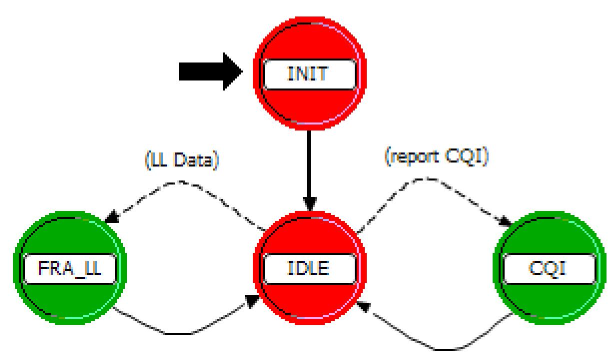

Figure 3: UE MAC Process Model

The UE "mac" process model is depicted in Figure 3. After performing the initializations steps, the machine proceeds to the IDLE state and waits for an interrupt. Two interrupts can happen in this state: reception of a data packet sent by the eNB or an expiration of a timer related to CQI updates.

eNB MAC Process Model

The "mac" process at the eNB is responsible for handling incoming packets from the source, processing CQI reports, and most importantly scheduling the control (PDCCH) and data (PDSCH) channels. As a result of the scheduling, TB (Transport Blocks) are created and sent over the PDSCH. In order to allow easy changes to the scheduling algorithm, the scheduling is done at a child process that is invoked at each TTI (Time Transmission Interval). The process model is shown in Figure 4, while an example of a scheduling child process is shown in Figure 5.

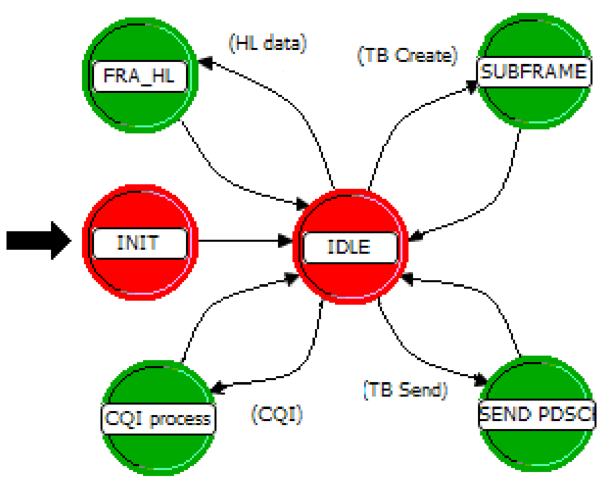

Figure 4 eNB MAC Process Model

After performing the initialization (related to reading LTE parameters, calculations on the available Resource Blocks) the machine proceeds to the ILDE state where it waits for an interrupt. Four interrupts can happen:

1. When a packet arrives from the traffic source, the process places the packet in the appropriate bearer buffer (RLC buffer). These buffers can have maximum of 1500 packets.
2. When a CQI report arrives, it is processed and stored in the scheduler database. The MCS (Modulation and Coding Scheme) is updated for each UE. In this phase of the project, the AMC (Adaptive Modulation and Coding) is based solely on the reported CQI value. The MCS is used in order to determine the TB size according to [11].
3. At the beginning of each subframe, a TB Create event is triggered, which in turn invokes the appropriate child process that created the TBs.
4. As soon as the control is returned to the master process, the machine proceeds to the SEND state, where the TBs are forwarded to the "phy" process in order to be transmitted over the PDSCH.

The scheduler process is responsible for deciding which UE will be scheduled in the next TTI, and for multiplexing the logical channels over the transport channels. For simplicity, each UE is configured with one logical channel. Each scheduler maintains a certain database of the UEs such as type of service, CQI reports, etc., in order to make a scheduling decision.

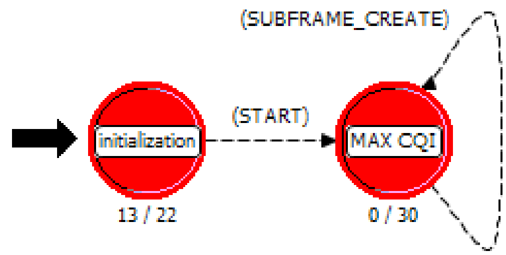

Figure 5 MAX CQI Scheduler Process Model

Two scheduling process models have been developed. The first one, "MAX CQI" (depicted in Figure 5), has only one criterion: the max CQI. As a CQI report arrives, it is inserted in the list of UEs such that the list remains sorted according to the CQI value. Then the scheduler considers the UE from the head of the list and schedules them. Additionally, one UE will not be assigned all available resource blocks (RB) if there is space on the PDCCH for new UEs, and these UEs have data to download. This way the "MAX CQI" scheme considered in this project provides some fairness to users, such that one user cannot be assigned all RB within one TTI.

The simulation analysis for "MAX CQI" shows that when UEs have a relatively small transmission buffer size but high SNR, this leads to lower PDSCH utilization. This is especially noticeable when UEs with VoIP services have higher SNR. Therefore, the buffer-aware scheduling scheme has been taken into consideration. Beside the CQI, the scheduler considers the size of the RLC buffer. The UEs that have a higher buffer size and CQI index take precedence. Additionally, in order to provide QoS awareness, the services are grouped in different QoS classes. Two schemes have been implemented where the prioritization of different services is presented, shown in Table 2.

Scheme	VoIP	Video	HTTP	FTP
TX 2 Classes	Class 1		Class 2	
TX 4 Classes	Class 1	Class 2	Class 3	Class 4

Table 2: QoS classes

Simulation Parameters

The simulations consider a single-cell multi-user scenario. The network topology can be seen in Figure 6. A scenario of 16 UEs, such that there are 4 UEs for each service class, and average distance to the eNB of 550 meters is considered.

The simulations are performed for minimum specified bandwidth for LTE and the ITU "Pedestrian A" channel model. For the DCI formats, the DCI Format 1 has been used in order to calculate the available CEE regions on the PDCCH, and it is assumed that a fixed 80% of the PDCCH is to be used for downlink assignments. Table 3 shows the rest of the system configuration parameters.

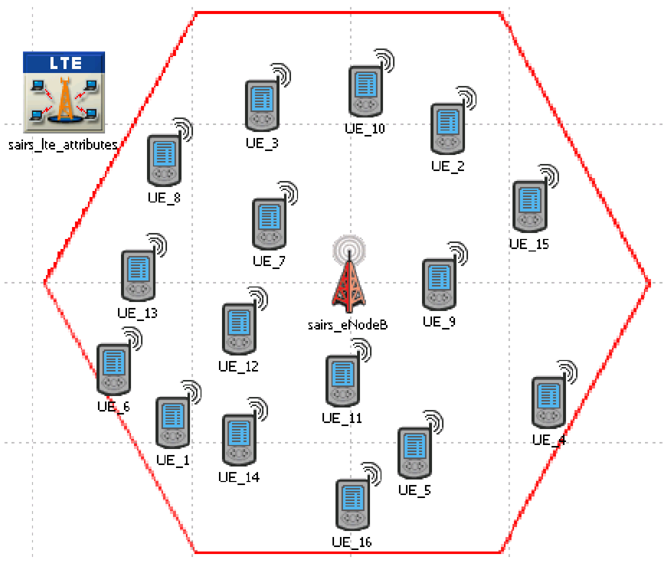

Figure 6: Network Topology

Parameter	Value
System Bandwidth	1.4 MHz
Multiplexing	FDD
Subcarrier Spacing	15kHz
Cycle Prefix	Normal
Number of eNB	1 (no Sectors)
Number of UE	16 users 4 VoIP, 4 Video, 4 HTTP and 4 FTP
Channel Profile	ITU Pedestrian A
RLC mode	Unacknowledged Mode
CQI measurements	wideband
Time window for measurement	1ms
Reporting interval	5 ms
Simulation Duration	1700 sec

Table 3: Simulation Parameters

Simulation Results

This section presents the results from the simulation based analysis for the scheduling schemes and configuration presented in the previous sections. The comparison metrics that are presented are the average achieved MAC layer throughput and delay for each class of service. Several simulations have been executed for different seed values. Figure 7 shows the average SNR for each service class for three simulation runs.

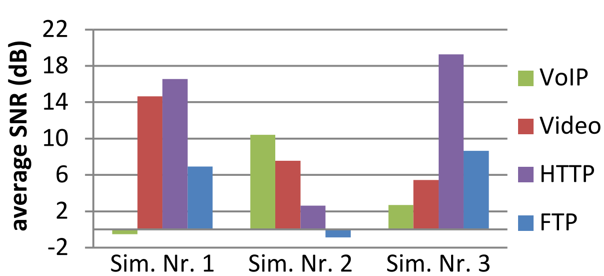

Figure 7: Average SNR distribution per service

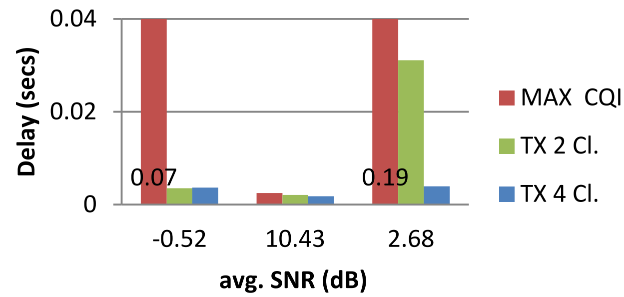

Figure 8: VoIP average delay

The performance degradation of VoIP services for the "MAX CQI" algorithm can be seen in Figure 8 where the average delay for VoIP service for different average SNR values is presented. As it can be seen for the figures, the "MAX CQI" results in higher delays, especially in the first and last simulation run since the average SNR is significantly lower in these two simulation runs. The "TX 4 Classes" improve the delay, since VoIP service will have priority over other services. The "TX 2 Classes" delays are slightly higher, since Video services will be scheduled before VoIP services, as the data size of the buffers for Video services are larger.

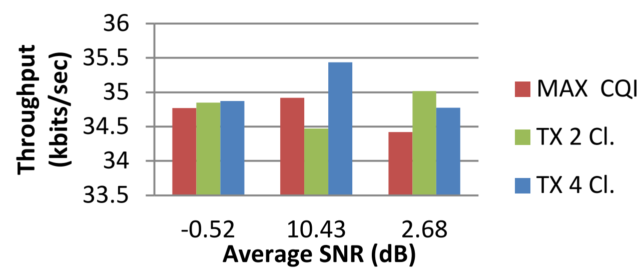

Figure 9: VoIP average throughput

The average throughput for VoIP service for different average SNR values can be seen in Figure 9. "TX 4 Classes" improve the average throughput for VoIP services due to the fact that the VoIP service class is assigned higher priority.

Figure 10 and Figure 11 show the average delay and throughput for the Video service class. For "MAX CQI", the delay is degraded in the third run since Video service needs to compete with FTP and HTTP service and has lower average SNR. Since the Video class service is separated in the "TX 2 Classes" and "TX 4 Classes" algorithms, and has higher priority over FTP and HTTP service, the delay is reduced.

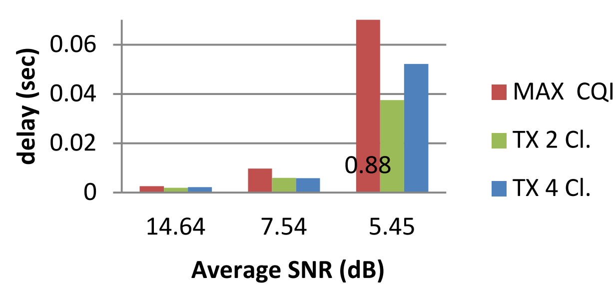

Figure 10: Video average delay

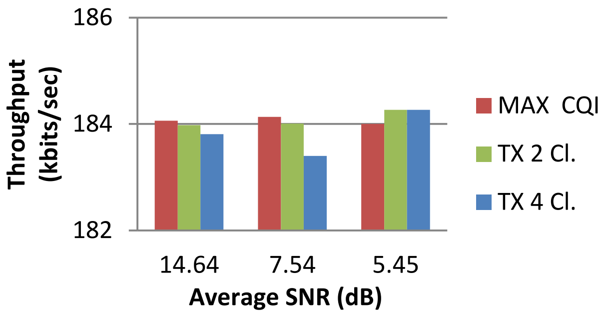

Figure 11: Video average throughput

The average throughput for the Video service in the first simulation run is better with the "MAX CQI" since, in the other two algorithms, the VoIP will have priority over the Video services. In the third simulation run, the average throughput is improved with "TX 2 Classes" and "TX 4 Classes" since the Video service will have higher priority over the HTTP service class that has the highest average SNR.

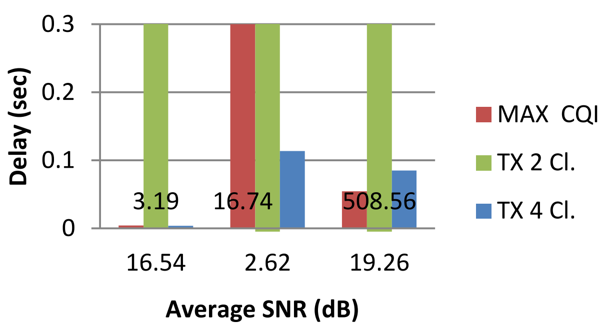

Figure 12: HTTP average delay

Figure 12 and Figure 13 show the average delay and throughput for HTTP service. As can be seen from the figures, the worst case is for "TX 2 Classes" because most of the time FTP service will take precedence over HTTP service flows. The reason for this is that the average buffer sizes for FTP flows will be larger than the buffer sizes for HTTP services most of the time. Statistics of the buffer sizes for FTP and HTTP services can be seen in Figure 13 (similar results were achieved for the other two simulation runs). "TX 4 Classes" improves the delay and throughput, with the exception of the third simulation. The reason for that is the fact that the average SNR for HTTP is the highest; therefore HTTP will have the highest priority over all other services. Still the average delay is not highly degraded by the "TX 4 Classes".

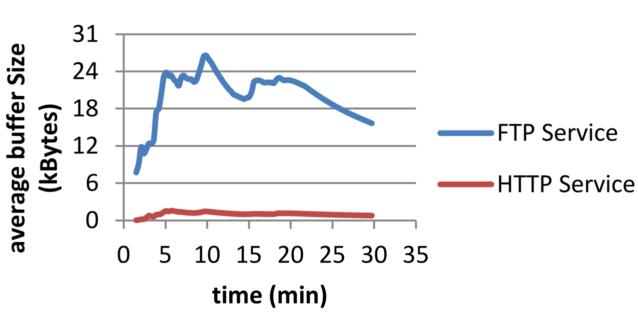

Figure 13. Buffer Size for Simulation Nr. 2

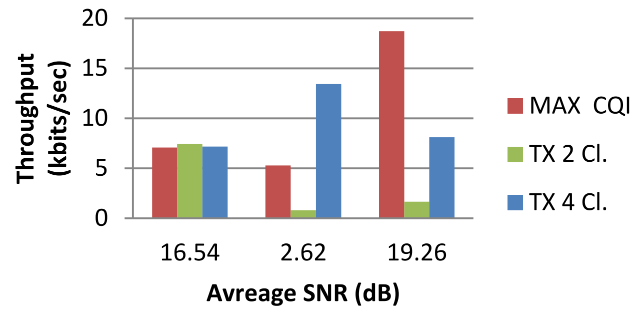

Figure 14: HTTP average throughput

Figure 14 and Figure 15 show the average delay and throughput for FTP service. For the first simulation run, the delay for FTP service is slightly improved with "TX 2 Classes" because FTP services will take precedence (because of the buffer size) over Video service which has the highest SNR for that simulation run.

As can be seen from the figures, "TX 2 Classes" and "TX 4 Classes" algorithms do not improve the performance for FTP services, since all other services will take precedence over the FTP service. Even more so in the third simulation run, the degradation of the delay is higher. This is because the buffers of VoIP and Video service flows will be slowly reduced with the transmissions due to the low MCS used. Therefore, the FTP services will be scheduled less frequently.

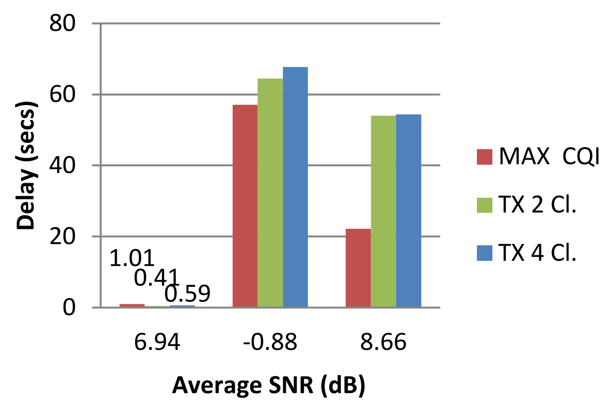

Figure 15: FTP average delay

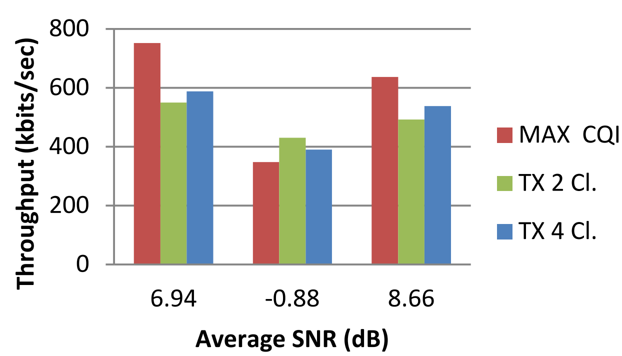

Figure 16: FTP average throughput

Conclusion

This paper elaborates on the LTE Downlink Scheduling Framework and presents an OPNET model for the evaluation of scheduling algorithms. This model has been used to study the impact of channel-aware, buffer-aware, and QoS-aware scheduling on different services. Two different QoS classifications have been defined, and the results of the buffer and QoS-aware algorithm have been compared to the MAX CQI algorithm.

When VoIP and Video services are grouped in one QoS class, the buffer aware scheduling improves the delay for VoIP service. When four different classes are considered, the delay for VoIP service is further improved, while voice service is not highly degraded. When HTTP and FTP services are grouped in one QoS class, HTTP service is highly degraded. The reason for this is the relatively large buffer size for FTP services as compared to HTTP services. Therefore, when these two services are considered as separate QoS classes, HTTP delays are improved. The buffer-aware scheduling algorithm presented in this paper has improved performance for VoIP, Video, and HTTP services, but FTP services have been highly degraded. Therefore, this algorithm needs to be further improved in order to satisfy QoS requirements for FTP services, as well.

In this phase of the project, only wideband measurements have been considered. In the future, we plan to include sub-band measurements. Additionally, since no packet loss has been considered, the HARQ retransmission information has not been taken into consideration for the scheduler, and it is left for future improvements.

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